TWI

Welding Inspection

Metallurgy

Course Reference WIS 5

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Steel Weld Metallurgy

- **Carbon:** Major element in steels, influences strength,toughness and wear
- **Manganese:** Secondary only to carbon for strength, hardenability , secondary deoxidiser and also acts as a desulphuriser.
- **Silicon:** Primary deoxidiser,hardenability
- **Molybdenum:** Effects hardenability, and has high creep strength at high temperatures. Steels containing molybdenum are less susceptible to temper brittleness than other alloy steels.
- **Chromium:** Widely used in stainless steels for corrosion resistance, increases hardness and strength but reduces ductility.
- **Nickel:** Used in stainless steels, high resistance to corrosion from acids, increases strength and toughness

Steel Weld Metallurgy

- **Aluminium:**Deoxidation
- **Sulfur:** Machineability
- **Tungsten:** High temperature strength
- **Titanium:** Elimination of carbide precipitation
- **Vanadium:** Fine grain – Toughness
- **Cooper:** Corrosion resistance and strength

Steel Weld Metallurgy

The grain structure of steel will influence its weldability, mechanical properties and in-service performance. The grain structure present in a material is influenced by:

- The type and number of elements present in the material
- The temperature reached during welding and or PWHT.
- The cooling rate after welding and or PWHT

Heat Affected Zone

The parent material undergoes microstructure changes due to the influence of the welding process. This area, which lies between the fusion boundary and the unaffected parent material, is called the heat affected zone (h.a.z.). The extent of changes will be dependent upon the following

- Material composition
- Cooling rate, fast cooling higher hardness
- Heat input, high heat inputs wider HAZ
- The HAZ can not be eliminated in a fusion weld

Heat Input

Amps = 200 Volts = 32

Travel speed = 240 mm/min

$$\text{Heat input} = \frac{\text{Amps x volts}}{\text{Travel speed mm/sec X 1000}}$$

$$\text{Heat input} = \frac{200 \text{ X } 32 \text{ X } 60}{240 \text{ X } 1000}$$

Heat input = 1.6 kJ/mm

Heat Input

High heat input - slow cooling

- Low toughness
- Reduction in yield strength

Low heat input - fast cooling

- Increased hardness
- Hydrogen entrapment
- Lack of fusion

Carbon Equivalent

- The *CE* of steel primarily relates to its hardenability.
- Higher the *CE*, lower the weldability
- Higher the *CE*, higher the susceptibility to brittleness
- The *CE* of a given material depends on its alloying elements
- The *CE* is calculated using the following formula

$$\mathbf{CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}}$$

$$\mathbf{CE = C + \frac{Mn}{6}}$$

Typical Elements in C/CMn Steel

- Iron (Fe): 97%
- Carbon (C): 0.12%
- Manganese (Mn): 1.3%
- Chromium (Cr):
- Molybdenum (Mo):
- Nickel (Ni)
- Silicon (Si)
- Aluminum (Al)

$$\mathbf{CE = C + \frac{Mn}{6}}$$

$$\mathbf{CE = 0.12 + \frac{1.3}{6}}$$

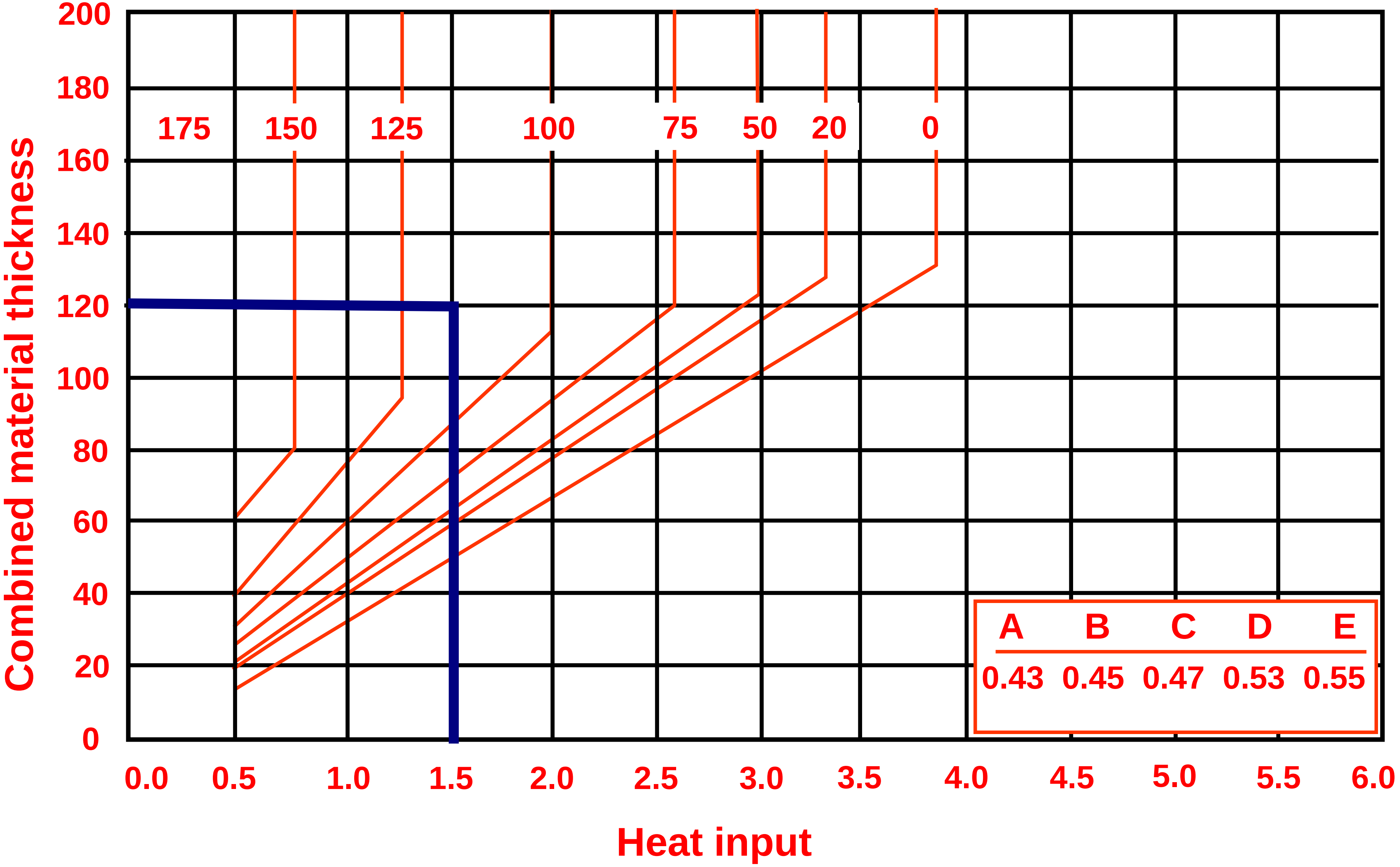
$$\mathbf{CE = 0.33\%}$$

Pre Heat

Preheat temperatures are arrived by taking into consideration the following:

- The heat input
- The carbon equivalent (*CE*)
- The combined material thickness
- The hydrogen scale required (A, B, C, D)

Pre Heat Comparison Chart



A	B	C	D	E
0.43	0.45	0.47	0.53	0.55

Pre Heat

Advantages of preheat

1. Slows down the cooling rate, which reduces the risk of hardening
2. Allows absorbed hydrogen a better opportunity of diffusing out, thereby reducing the risk of cracking
3. Removes moisture from the material being welded
4. Improves overall fusion characteristics
5. Lowers stresses between the weld metal and parent material by ensuring a more uniform expansion and contraction

Methods of Measuring Pre Heat

- Temperature indicating crayons (Tempil sticks®)
- Thermocouples or touch pyrometers
- At intervals along of around the joint to be welded
- The number of measurements taken must allow the inspector to be confident that the required temperature has been reached
- In certain cases the preheat must be maintained a certain distance back from the joint faces
- If a gas flame is being used for preheat application the temperature should be taken form the opposite side to the heat source
- If this is not possible time must be allowed before taking the preheat temperature e.g 2 mins for 25mm thickness

Cracks

Process Cracks

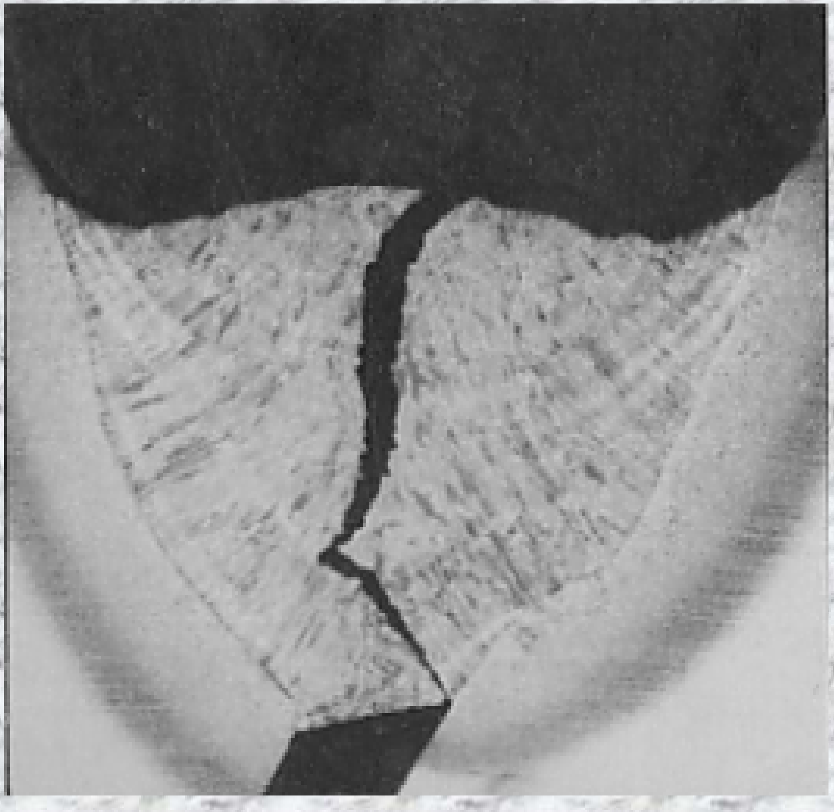
- Hydrogen induced cold cracking (HICC)
- Solidification cracking (Hot Tearing)
- Lamellar tearing
- Re heat cracking

Hydrogen Cracking

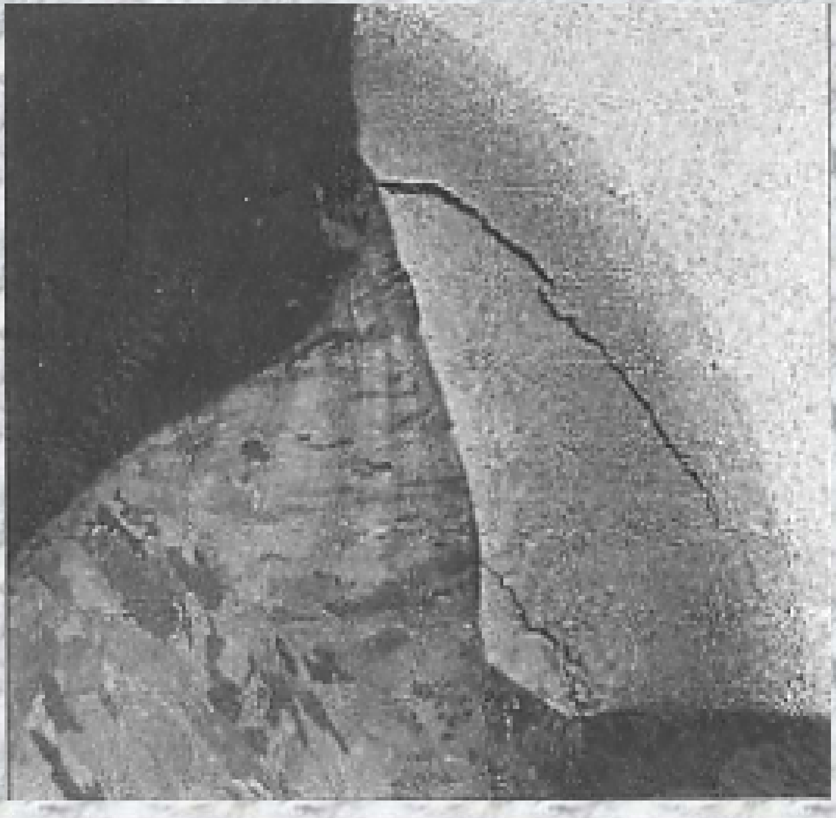
The four essential factors for cracking to occur

- Susceptible grain structure
- Hydrogen
- Temperature less than 200^{o}C
- Stress

Hydrogen Cracking



Hydrogen induced weld metal cracking



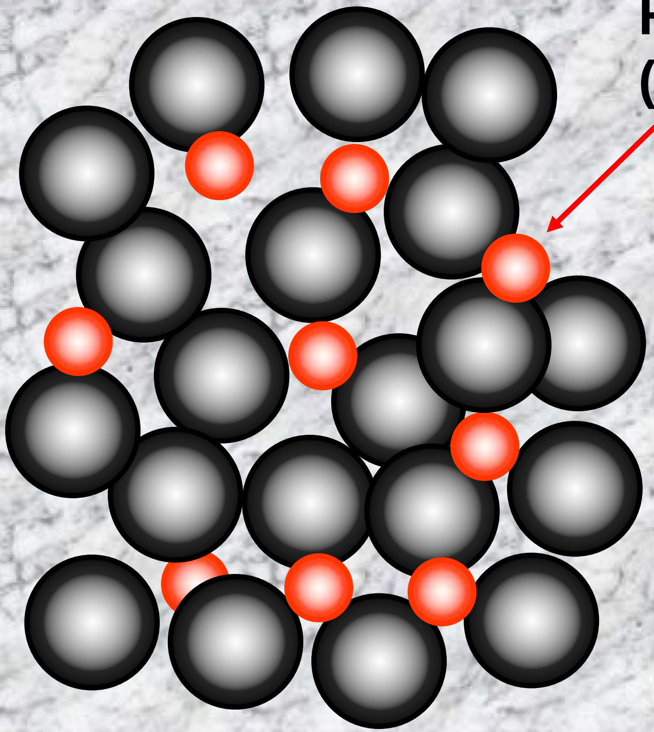
Hydrogen induced HAZ cracking

Hydrogen

- Hydrogen smallest atom known atomic number 1
- Hydrogen enters the weld via the arc
- Diatomic element (H+H = H_2) at room temperature
- Source of hydrogen may be from moisture on the parent material, damp welding fluxes or from the parent material

Hydrogen Cracking

Above 200°C

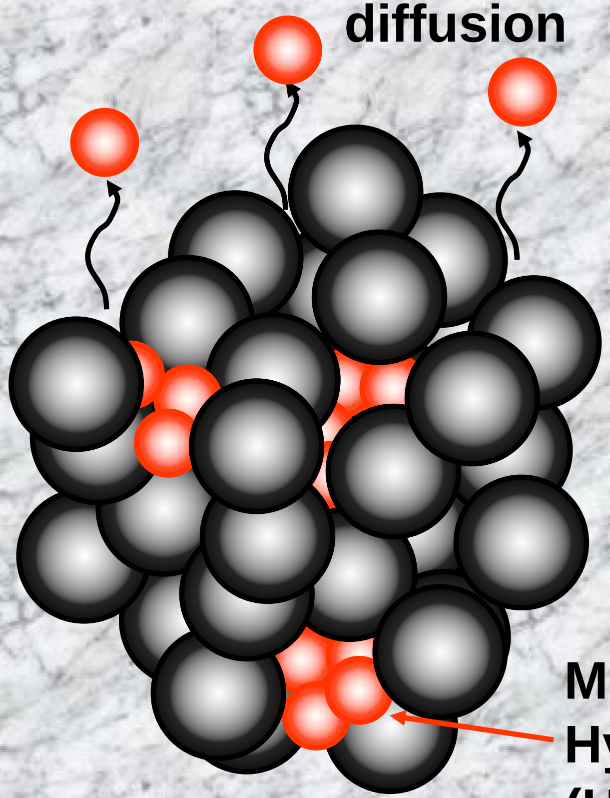


Atomic Hydrogen (H)

Steel in expanded condition

Below 200°C

Hydrogen diffusion



Molecular Hydrogen (H_2)

Steel under contraction

Hydrogen Cracking

Precautions for controlling hydrogen cracking

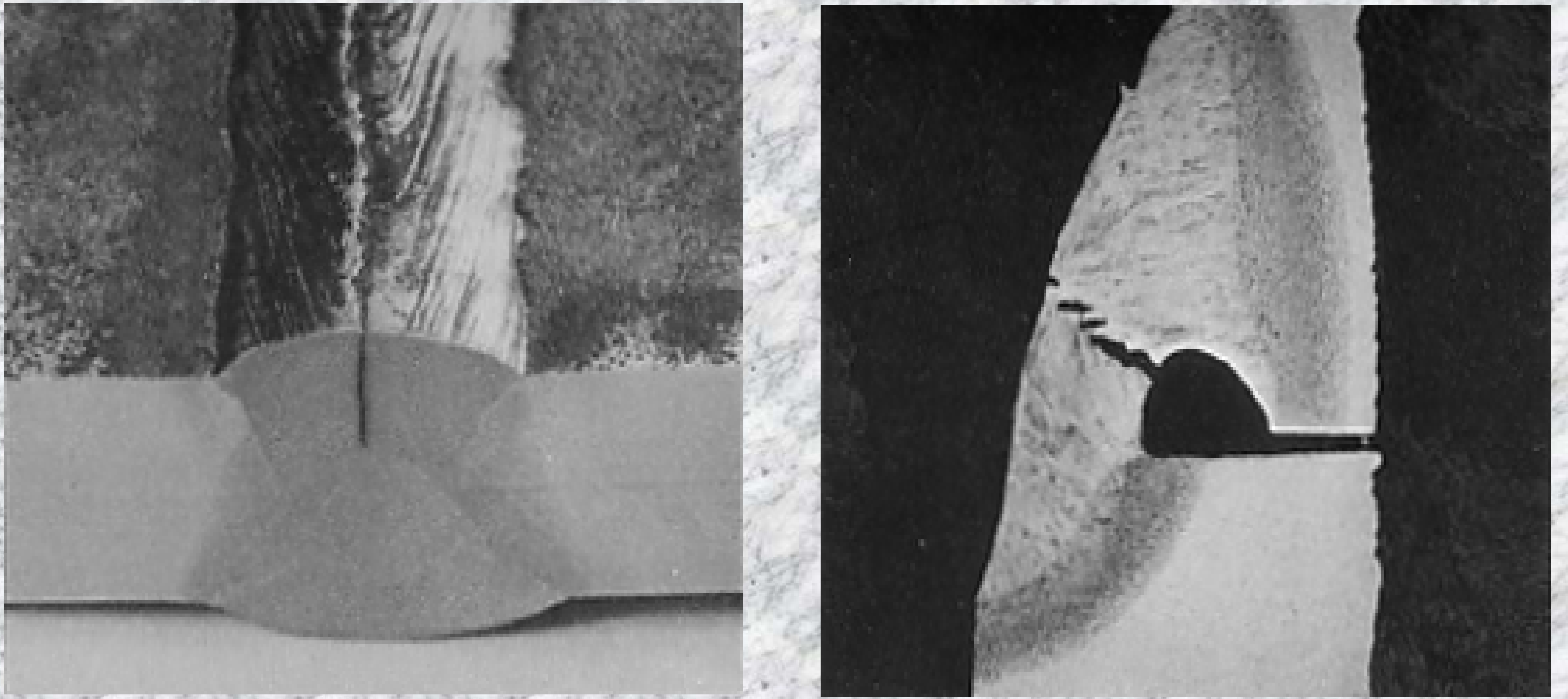
- Pre heat, removes moisture from the joint preparations, and slows down the cooling rate
- Ensure joint preparations are clean and free from contamination
- The use of a low hydrogen welding process
- Ensure good fit-up as to reduced stress
- The use of a PWHT

Solidification Cracking

Essential factors for solidification cracking to occur

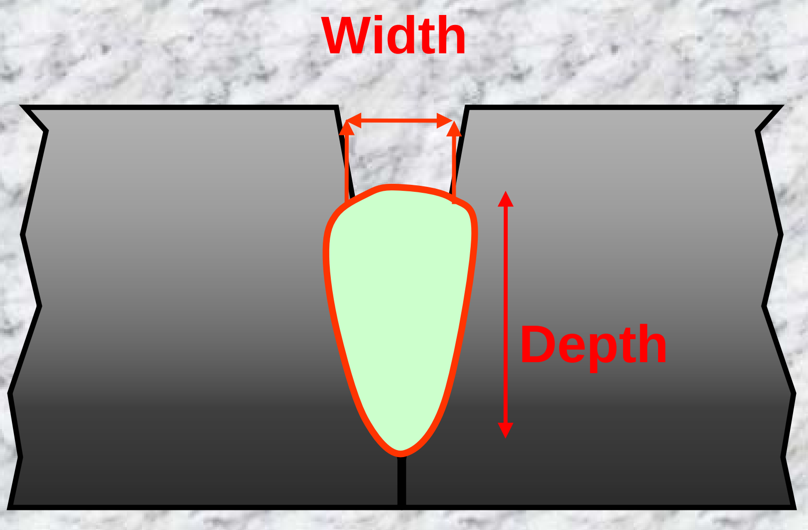
- Impurities such as sulphur, phosphorous and carbon
- The amount of stress/restraint
- Most commonly occurs in sub-arc welded joints
- Joint design depth to width ratios

Solidification Cracking



Weld Centerline

Solidification Cracking

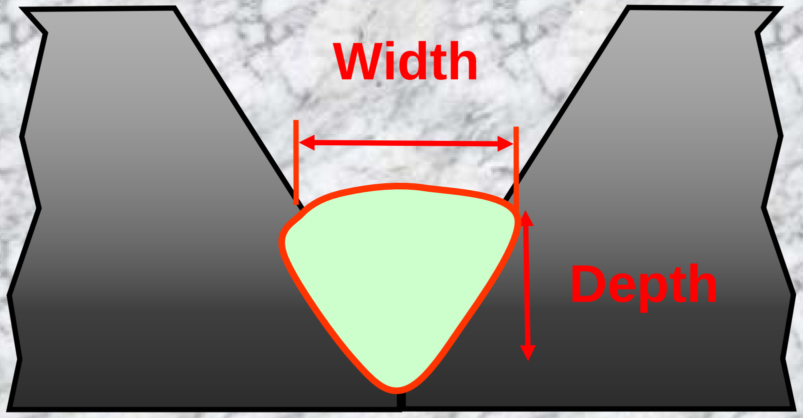


Incorrect

Weld depth Weld width

Cracking likely

**Higher dilution levels
faster cooling**



Correct

Weld depth Weld width

Cracking unlikely

**Lower dilution levels
slower cooling**

Solidification Cracking

Precautions for controlling solidification cracking

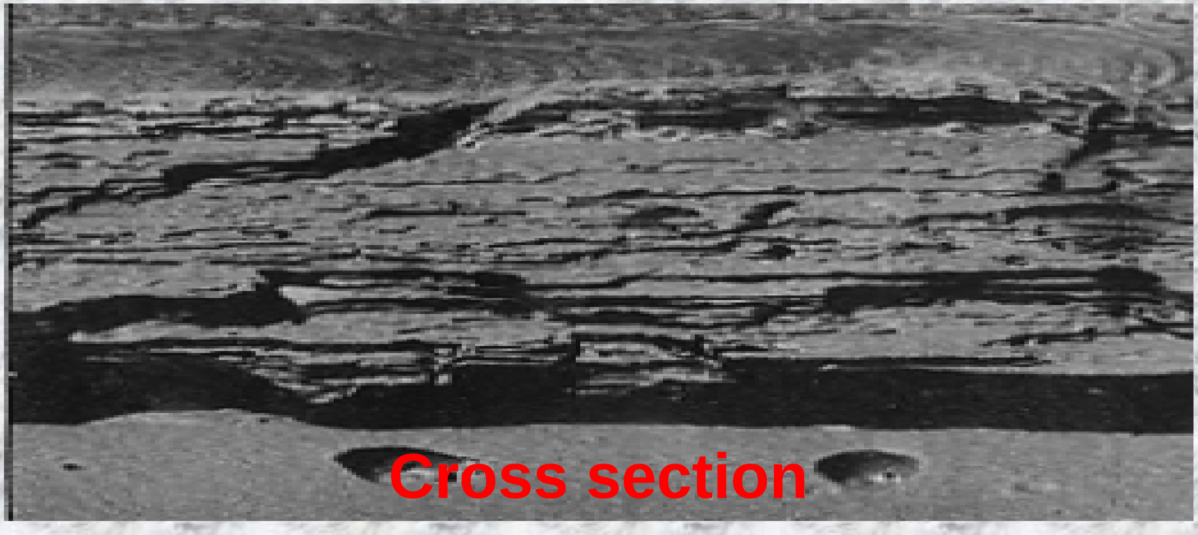
- The use of high quality parent materials, low levels of impurities
- Joint design selection depth to width ratios
- Minimise the amount of stress / restraint acting on the joint during welding
- The use of high manganese and low carbon content fillers / electrodes
- Clean joint preparations

Lamellar Tearing

- Lamellar tearing has a step like appearance due to the solid inclusions linking up under the influences of welding stresses
- It forms when the welding stresses act in the short transverse direction of the material (through thickness direction)
- Low ductile materials containing high levels of impurities are very susceptible
- The short tensile test or through thickness test is a test to determine a materials susceptibility to lamellar tearing

Lamellar Tearing

Step like appearance



Cross section

Lamellar Tearing

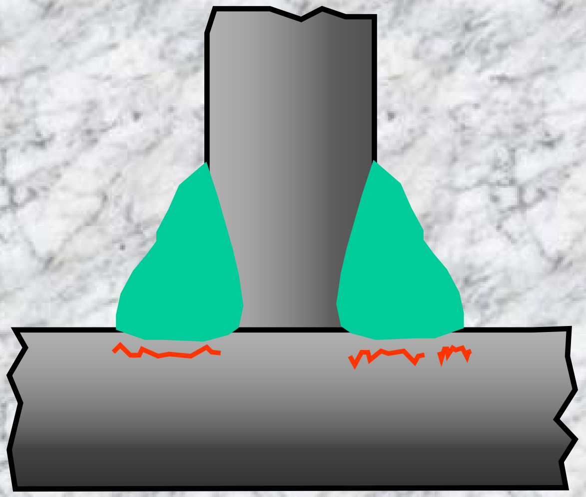
Factors for lamellar tearing to occur

- Low quality parent materials, high levels of impurities of nonmetallic inclusion such as sulphides and silicates.
- Joint design, direction of stress
- The amount of stress acting across the joint during welding
- Hydrogen levels in the parent material

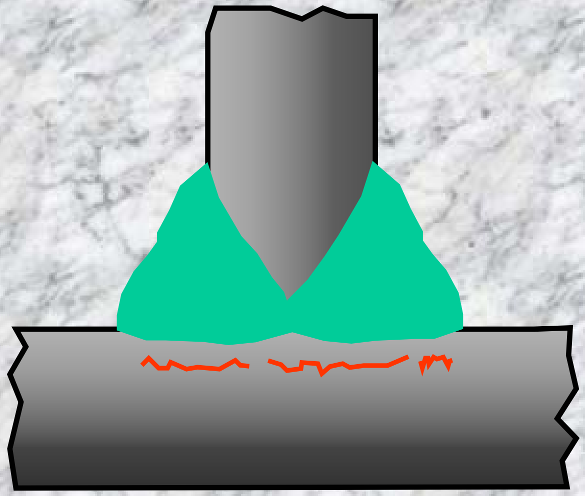
Note: very susceptible joints may form lamellar tearing under very low levels of stress

Lamellar Tearing

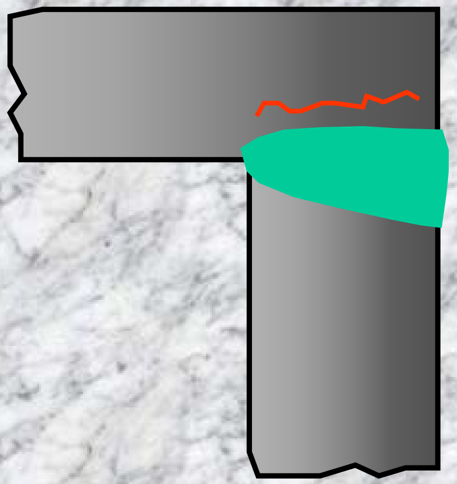
Susceptible joint types



Tee fillet weld

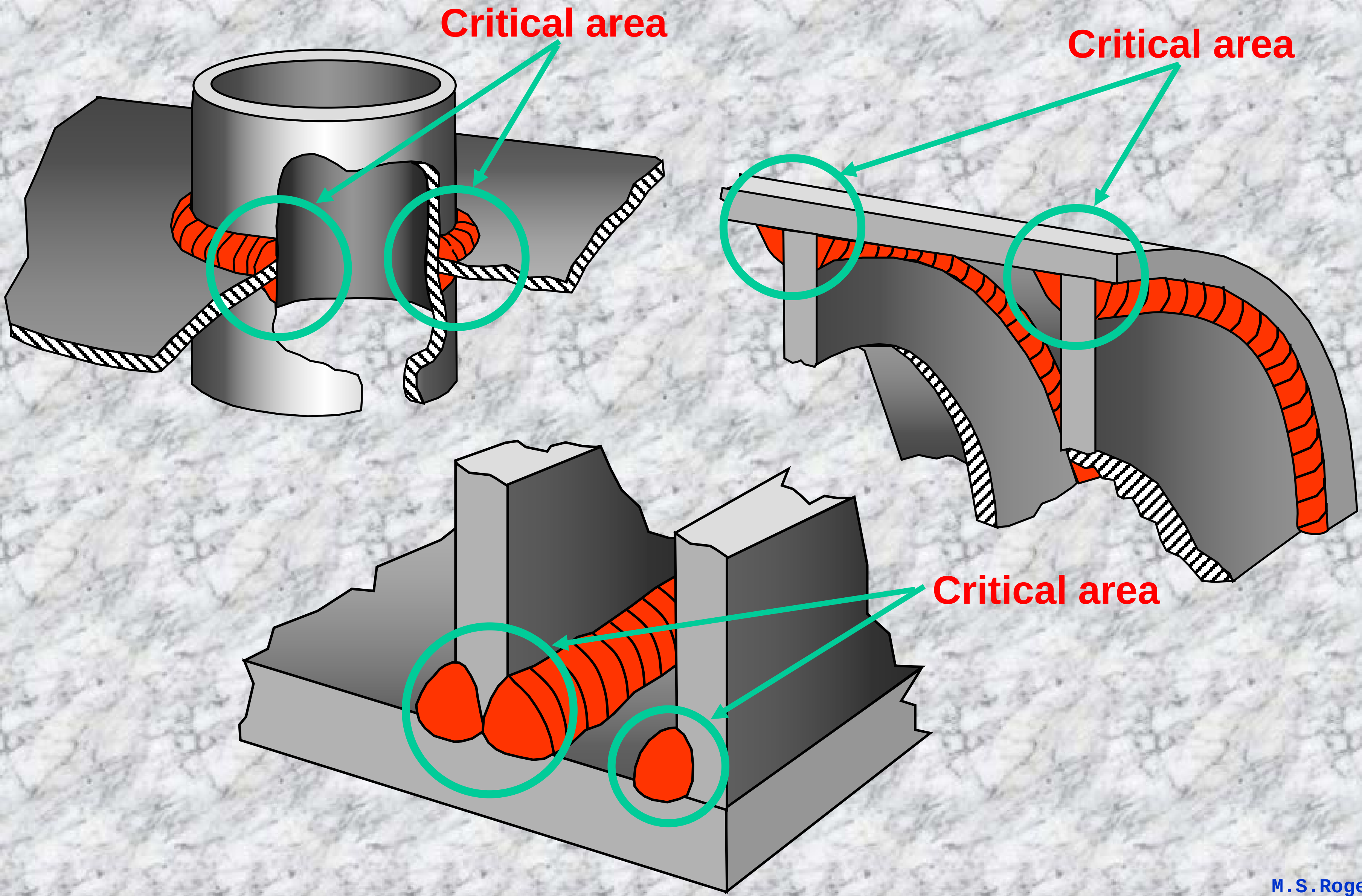


Tee butt weld
(double-bevel)



Corner butt weld
(single-bevel)

Lamellar Tearing



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Lamellar Tearing

Precautions for controlling lamellar tearing

- The use of high quality parent materials, low levels of impurities
- Joint design selection
- Minimise the amount of stress / restraint acting on the joint during welding
- The use of buttering runs
- Hydrogen precautions

In-Service Cracks

- Fatigue cracks
- Weld decay in austenitic stainless steels
- Stress corrosion cracking
- Creep failure

Fatigue Cracks

- Fatigue cracks occur under cyclic stress conditions
- Fracture normally occurs at a change in section, notch and weld defects i.e stress concentration area
- All materials are susceptible to fatigue cracking
- Fatigue cracking starts at a specific point referred to as a initiation point
- The fracture surface is smooth in appearance sometimes displaying beach markings
- The final mode of failure may be brittle or ductile or a combination of both

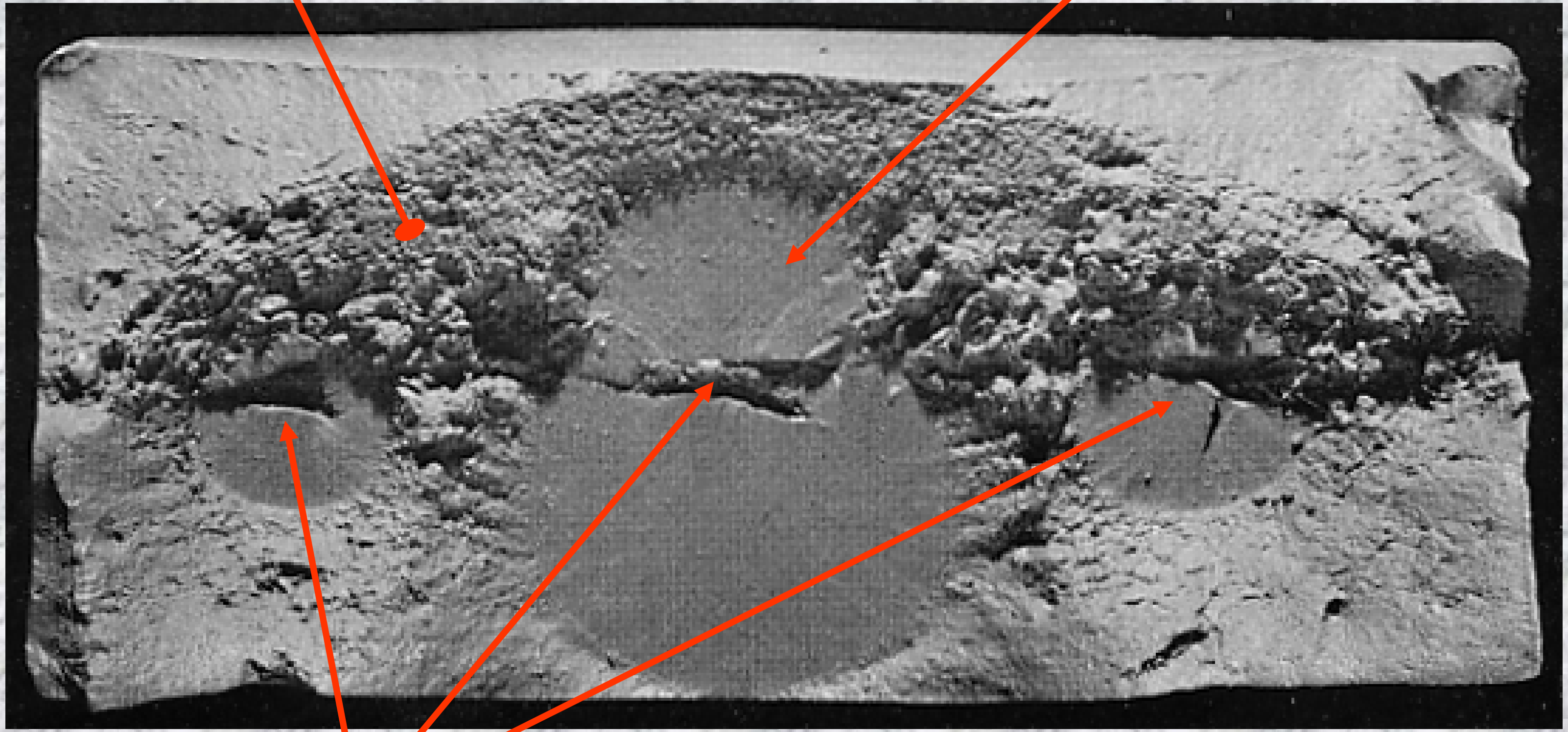
Precautions against Fatigue Cracks

- Toe grinding, profile grinding.
- The elimination of poor profiles
- The elimination of partial penetration welds and weld defects
- Operating conditions under the materials endurance limits
- The elimination of notch effects e.g. mechanical damage cap/root undercut
- The selection of the correct material for the service conditions of the component

Fatigue Cracks

Secondary mode of failure ductile fracture rough fibrous appearance

Fatigue fracture surface smooth in appearance



Initiation points / weld defects

Weld Decay

- Weld decay may occurs in austenitic stainless steels
- Also know as knife line attack
- Chromium carbide precipitation takes place at the critical range of 600-850°C
- At this temperature range carbon is absorbed by the chromium, which causes a local reduction in chromium content
- Loss of chromium content results in lowering the materials resistance to corrosion attack allowing rusting to occur

Precautions for Weld Decay

- The use of a low carbon grade stainless steel e.g. 304L, 316, 316L
- The use of a stabilized grade stainless steel e.g. 321, 347, 348 recommended for severe corrosive conditions and high temperature operating conditions
- Standard grades may require PWHT, this involves heating the material to a temperature over 1100^{o}C and quench the material, this restores the chromium content at the grain boundary, a major disadvantage of this heat treatment is the high amount of distortion